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1 Midday Recovery in Absorption 6

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Abstract

Balloon and riometer observations of the end-phase of a PCA midday recovery indicate that the increase in absorption was accompanied by corresponding changes in particle flux, with the high energy portion of the spectrum increasing before the lower energy end.

Introduction

The ionospheric absorption during solar cosmic ray events is known to show two types of daily variation. One is a nighttime phenomenon, during which the absorption magnitude is low, due to absence of photodetachment of negative ions in the D-region. The other is a daytime feature, at least for a significant fraction of the PCA events to date, centered around 10-12 hours local time, when the absorption magnitude is low for about two hours. The midday recoveries, as they are termed, are restricted in latitude, occurring primarily at the equatorward edge of the polar cap regions, and are variable in time from one day to the next in a given PCA event. The current interpretation (Leinbach, 1961) is that midday recoveries result from local time dependent changes in the effective geomagnetic cutoff energy for particles reaching the edges of the polar cap regions.

In offering this interpretation, Leinbach (1961) cited results of balloon observations (Winckler et al, 1961) of solar cosmic ray variations over Minneapolis, Minnesota and riometer observations (Fleischer and Lichtenstein, 1959) of cosmic radio noise absorption at Troy, New York during the great PCA event of July 14, 1959. While features of these measurements do provide support to the argument, they suffer to a certain extent from being made at two widely separated locations.

In the present paper, additional observations on midday recoveries are reported which support Leinbach's earlier interpretation. They were obtained during the September 2, 1966 PCA event and involve balloon and riometer data from essentially the same location (College, Alaska).

Observations

The September 2, 1966 PCA event began with a class 3 solar flare at 0538 UT and was followed by strong auroral and magnetic activity beginning on the night of September 3. Throughout this whole period, riometer and balloon observations were made in Alaska. A summary of the riometer data from several sites is given in Figure 1, showing strong ionospheric absorption during the daylight hours for two days following the flare. Of particular interest here is the distinct midday recovery in absorption which began around 1930 UT and returned to a higher level again at about 2230 UT on September 2. These variations occurred during a period of relative magnetic quiet, in contrast to the absorption features of the following day when auroral absorption played a strong role.

Several balloon flights were made during this period. Characteristics of the radiation detectors on their flights are summarized in Table I. The high altitude winds at this time were such as to carry the balloons essentially parallel to a line of geomagnetic latitude at about 10 knots.

Flight 6 was launched without knowledge of the PCA event and its purpose was to pursue auroral x-ray time variations associated with the late phases of magnetic activity starting with the sudden commencement storm of 1112 UT on August 30. The flight carrying a NaI(Tl) scintillation counter reached an atmospheric depth of 10 gm/cm^2 and showed enhanced, but relatively steady, counting rates until cut down at 0220 UT on September 3. This was in sharp contrast to Flight 5 launched the preceding night which showed larger, more rapid changes in counting rate. These flight records are shown in Figure 2 and the degree of geomagnetic

disturbance during the scintillation counter flights is given by the 3-hour K-indices from the College Magnetic Observatory in Table II. Comparison of the balloon data with corresponding magnetograms indicates that Flight 5 counted only auroral x-rays while the steady, enhanced rates of Flight 6 resulted primarily from solar cosmic ray effects, with modest auroral contamination between 1600 UT and 1930 UT from minor ($\leq 200\gamma$) magnetic bay activity.

Flight 7, carrying a counter telescope and a single Geiger counter to examine charged particle fluxes in the PCA event, reached an atmospheric depth of 7 gm/cm^2 at 2130 UT on September 2. These detectors showed the presence of energetic solar protons, even though reaching ceiling altitude 16 hours after the flare began, with counting rates rising above galactic cosmic ray background levels for atmospheric depths less than 25 gm/cm^2 . After 2130 UT, the excess single counter and telescope rates varied together, with a ratio of 3.4 ± 0.1 , and declined steadily throughout the remainder of the flight except for a brief increase around 2230 UT, as shown in Figure 3.

In contrast to the scintillation counter on Flight 6 which responded to energy losses in the crystal from charged particles as well as energetic photons (with efficiencies ranging from 100% for energies below 100 keV to about 30% for energies near 1 MeV), the gas-filled counters on Flight 7 counted primarily charged particles passing through their sensitive volumes (with photon efficiencies less than 1%). Thus, taking the depth variation of the excess counter and telescope rates gives a range spectrum of the charged

particles and this, in turn, gives a differential energy spectrum (Pfofzer et al, 1962). For the ascent portion of Flight 7, from 25 gm/cm² to 7 gm/cm², the atmospheric depth variation yielded an excess counting rate increasing as $P^{-3.2}$, where P is in gm/cm², and corresponds to a steep proton spectrum

$$N(E)dE = KE^{-6.3}dE$$

between 90 MeV and 200 MeV. With this form of the spectrum and the telescope geometry, the vertical proton flux at 2130 UT amounted to 2.6 protons/cm²-sec-ster above 90 MeV.

At the time Flight 7 reached ceiling altitude, Flight 6 was still at 10 gm/cm² atmospheric depth and counting about 530 counts/sec above background. Taking the proton spectrum, adjusted for the 10 gm/cm² depth of the detectors on Flight 6, and using the geometry of the scintillation counter, calculation shows that protons penetrating the crystal contributed only ~23 counts/sec to the excess rate of 530 counts/sec at 2130 UT. Thus, except for the auroral contamination obvious by its temporal variation and association with magnetic bay activity, the enhanced rate of long duration on Flight 6 was due almost completely to nuclear gamma rays (Brown and D'Arcy, 1959; Bhavsar, 1961) from reactions between air nuclei and low-energy protons unable to penetrate to balloon depths.

Interpretation

Comparison of the counting rate variations on Flights 6 and 7 shows a more rapid decay for the penetrating proton component than the part of the spectrum below atmospheric cutoff which was observed indirectly through nuclear gamma rays. In particular, between 2130 UT and 0230 UT, the excess scintillator rate showed a net decline of only 10% while the telescope and Geiger counter rates had fallen off by $\sim 80\%$. Over this same time interval, the ionospheric absorption showed only a negligible change of +0.3 db. From this, it is evident that the low-energy portion of the proton spectrum was the one most closely related to the polar cap absorption. The degree to which this is the case is shown by comparing the time variation of the ratio of absorption to the square root of the excess counting rates for the charged particle detectors on Flight 7 and the scintillation counter on Flight 6. In principle, this ratio should be essentially constant if the radiation responsible for the absorption is correctly identified since the steady-state absorption is proportional to the electron density, or equivalently the square root of the ionization rate of the flux of particles in the absorbing region. Using 15-minute scalings from 2130 UT to 0200 UT and reducing the Geiger counter and scintillation counter data to a common basis by using counting rates per unit omnidirectional area of the detectors, the time variation of this ratio is given in Figure 4. This shows the ratio for the low-energy component changed by only $\sim \pm 10\%$ over this period while that for the high-energy component increased fairly steadily and changed by more than 100%, clearly indicating that

the low-energy flux was responsible for the absorption recorded by the College riometer.

Turning to that portion of the midday recovery when both Flights 6 and 7 were aloft, the riometer and balloon data indicate an increase in radiation influx after 2230 UT. Both the charged particle detectors on Flight 7 showed an increase in counting rate, lending confirmation that the excess influx was due to protons and not auroral x-rays. After the telescope and Geiger counter rates reached their peak values, the rates showed a continuation of the decline in intensity evident earlier; however, there was a net shift upward in the excess counting rates, not just a brief peak superimposed on the pattern of declining intensity. This is shown more clearly for the gamma ray data from Flight 6 in Figure 2, where the excess counting rate increased by $\sim 70\%$ between 2230 UT and 2300 UT and then showed a slow decay such as found earlier in the event.

A more detailed view of the variation in counting rates and absorption associated with the end of the midday recovery is given in the linear plot in Figure 5. Here, it is seen that both of the charged particle detectors showed an increase in counting rate starting at 2234 UT while the scintillator rate did not start to increase until after 2238 UT. This indicates an energy-dependence in the changes of particle influx, the intensity of the more energetic particles increasing some minutes before similar changes took place in the lower portion of the spectrum.

Discussion

Midday recoveries in absorption during solar cosmic ray events, since they are observed primarily at the lower edges of the polar caps, are difficult to study because of possible auroral contamination of the data from riometers and balloon-borne instruments. For the present event, however, the intrinsic features of the data as well as geomagnetic conditions around local noon may be used to argue strongly against any serious auroral x-ray contamination. Thus, both detectors sensitive to energetic charged particles showed an intensity increase at essentially the same time as the scintillation counter; in addition, the scintillation counter showed a relatively constant relation to the ionospheric absorption over a five hour period. For auroral x-ray events, the counter telescope would not have shown any variation in counting rate; also, the relationship between absorption and scintillator counting rates would show far more variability as well as much lower numerical values since auroral events generally show less absorption and yield far greater counting rates than those on Flight 6. (The x-ray and riometer data from Flight 5 show this, the $(\text{absorption})/(\text{excess flux})^{\frac{1}{2}}$ ratio ranging around 0.3 with considerable scatter.)

The level of geomagnetic disturbance, summarized earlier by K-indices, was too low to be responsible for any significant, sustained auroral x-ray effects either. This is indicated more clearly by the storm magnetograms in Figure 6, where the magnetic quiet around local noon (2200 UT) is shown together with some of the storm conditions which prevailed for the next two days.

With these arguments, it is clear that the changes in absorption and counting rates discussed above stemmed from changes in the solar cosmic ray flux reaching the atmosphere. Looking at the increases in absorption and counting rates during the end of the midday recovery, it is evident that additional particles were reaching the D-region. Since the higher energy portion of the spectrum increased first, and then was followed by lower energy particles some minutes later, the most plausible interpretation of this end-phase of a midday recovery is that due to Leinbach (1961), involving changes in the cutoff energy around local noon when the lines of force of the geomagnetic field pertaining to the station approach the solar direction. For a full midday recovery, instead of the end-phase that we observed, the diurnal variation in cutoff would presumably exclude the low energy end of the spectrum first and then return it last, as noted in this event.

The problem of anomalously low cutoffs for protons in the polar cap region has been under scrutiny for some time now. While the experimental facts are well established, only recently (Reid and Sauer, 1966) have model calculations been undertaken to explore this problem further. This current approach is to relate the depression in cutoff energy to the existence of the geomagnetic tail and the diurnal variation in cutoff, as demanded by midday recoveries in absorption, to the diurnal variation in the boundary of the stable trapping region for energetic electrons. Clearly, additional observations of the time variations of the low and high energy portions of the solar proton flux around local noon would be valuable in revealing if the full sense of a diurnal variation in cutoff is borne out.

References

- Bhavsar, P. D., "Gamma Rays from the Solar-Cosmic-Ray-Produced Nuclear Reactions in the Earth's Atmosphere and Lower Limit on the Energy of Solar Protons Observed at Minneapolis", J. Geophys. Res., 67, 2627, 1962
- Brown, R. R. and R. G. D'Arcy, "Observations of Solar Flare Radiation at High Latitude during the Period July 10-17, 1959", Phys. Rev. Letters, 3, 390, 1959
- Fleischer, R. and P. R. Lichtenstein, "18-Megacycle Cosmic Noise Intensities", Rensselaer Observatory Publ., No. 10, 1959
- Leinbach, H., "Some Observations of Daytime Recoveries during Polar Cap Absorption Events", Arkiv för Geofysik, 3, 427, 1961
- Pfotzer, G., A. Ehmert and E. Keppler, "Time Pattern of Ionizing Radiation at Balloon Altitudes in High Latitude", Max-Planck Institut für Aeronomie, August, 1962
- Reid, G. C. and H. H. Sauer, "The Influence of the Geomagnetic Tail on Low-Energy Cosmic Ray Cutoffs", Trans. A.G.U., 47, 55, 1966
- Winckler, J. R., P. D. Bhavsar and L. Peterson, "The Time Variations of Solar Cosmic Rays during July 1959 at Minneapolis", J. Geophys. Res., 66, 995, 1961

Table I

Detector Specifications

Detector	Geometry and Dimensions	Solid Angle Factor	Comments
NaI(Tl) Counter	cylinder 5.08 cm dia. 1.27 cm ht.	15.2 cm ² omnidirectional projected area	measured energy losses \geq 30 KeV on Flights 5 and 6
Geiger Counter	cylinder 6.5 length 1.9 cm dia.	11.2 cm ² omnidirectional projected area	used on Flight 7
Telescope	6.5 cm length 3.8 cm width 7.6 cm between axes of upper and lower trays	12.4 cm ² -ster for isotropic flux 10.6 cm ² -ster for Cos ³ θ flux	used on Flight 7

Table II

Geomagnetic K-Indices

Date	Hours (UT)							
	0-03	03-06	06-09	09-12	12-15	15-18	18-21	21-24
Sept. 1	-	-	-	6	5	5	4	3
2	2	2	1	1	3	4	4	3
3	2	-	-	-	-	-	-	-

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Figure Captions

- Figure 1 Riometer observations of ionospheric absorption during the September 2, 1966 PCA event. (College, 64.6° N mag. lat.; Kotzebue, 63.6° N mag. lat.; Healy, 63.5° N mag. lat.)
- Figure 2 Scintillation counter data from Flights 5 and 6, launched on September 1 and 2, respectively.
- Figure 3 Geiger counter and telescope counting rates for solar protons on the September 2, 1966 PCA event.
- Figure 4 Time variation of the ratio $\text{Abs}(\text{db})/(\text{counting rate})^{\frac{1}{2}}$ for the interval 2130-0230 UT of September 2-3, 1966. Top curve: Geiger counter; bottom curve: scintillation counter.
- Figure 5 Linear plot of the counting rate variations and absorption for 2200-2300 UT on September 2, 1966. Top curves: radiation detectors; bottom curve: riometer.
- Figure 6 Storm magnetograms from College Magnetic Observatory; September 2-3, 1966.

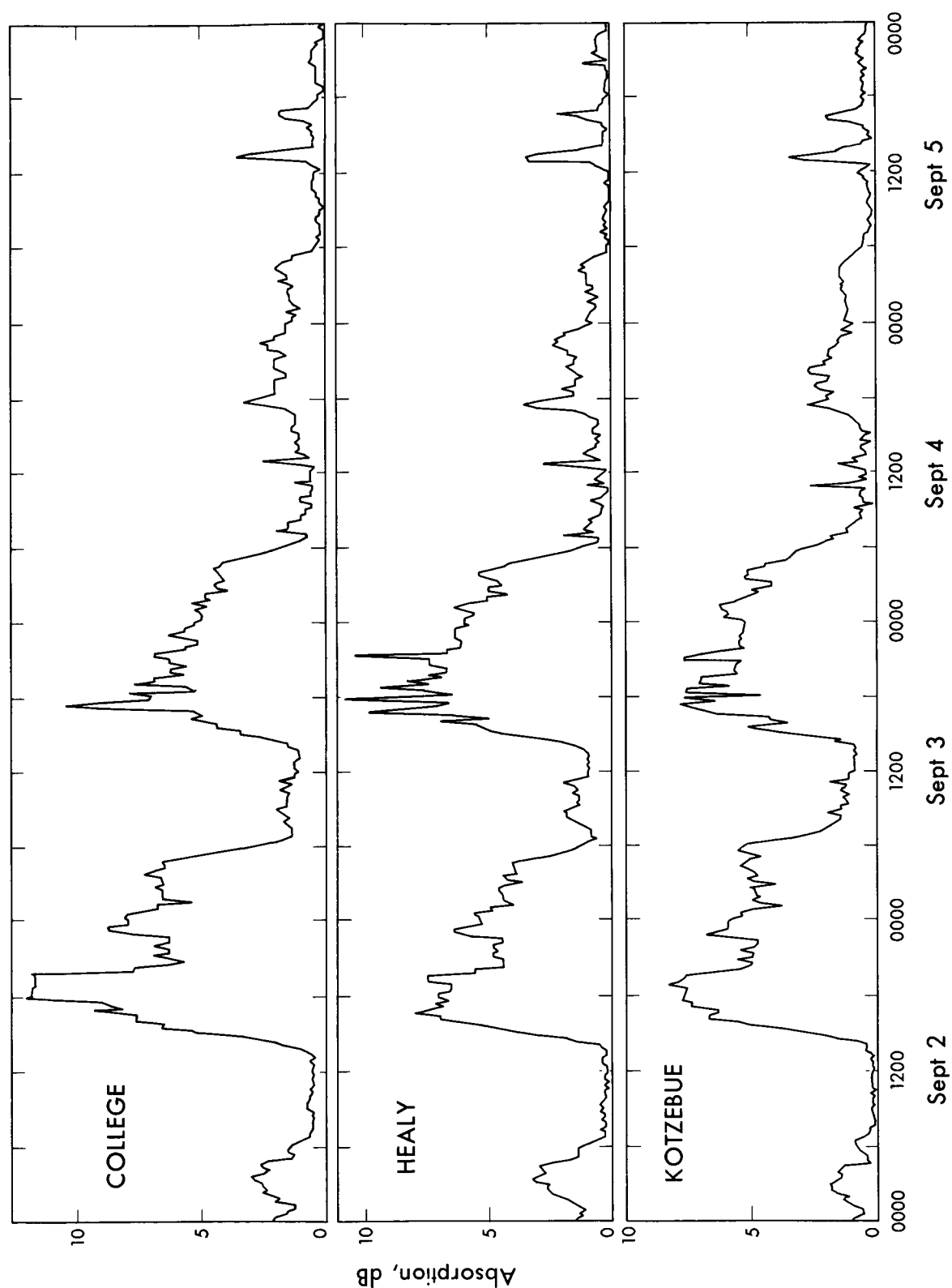


Figure 1

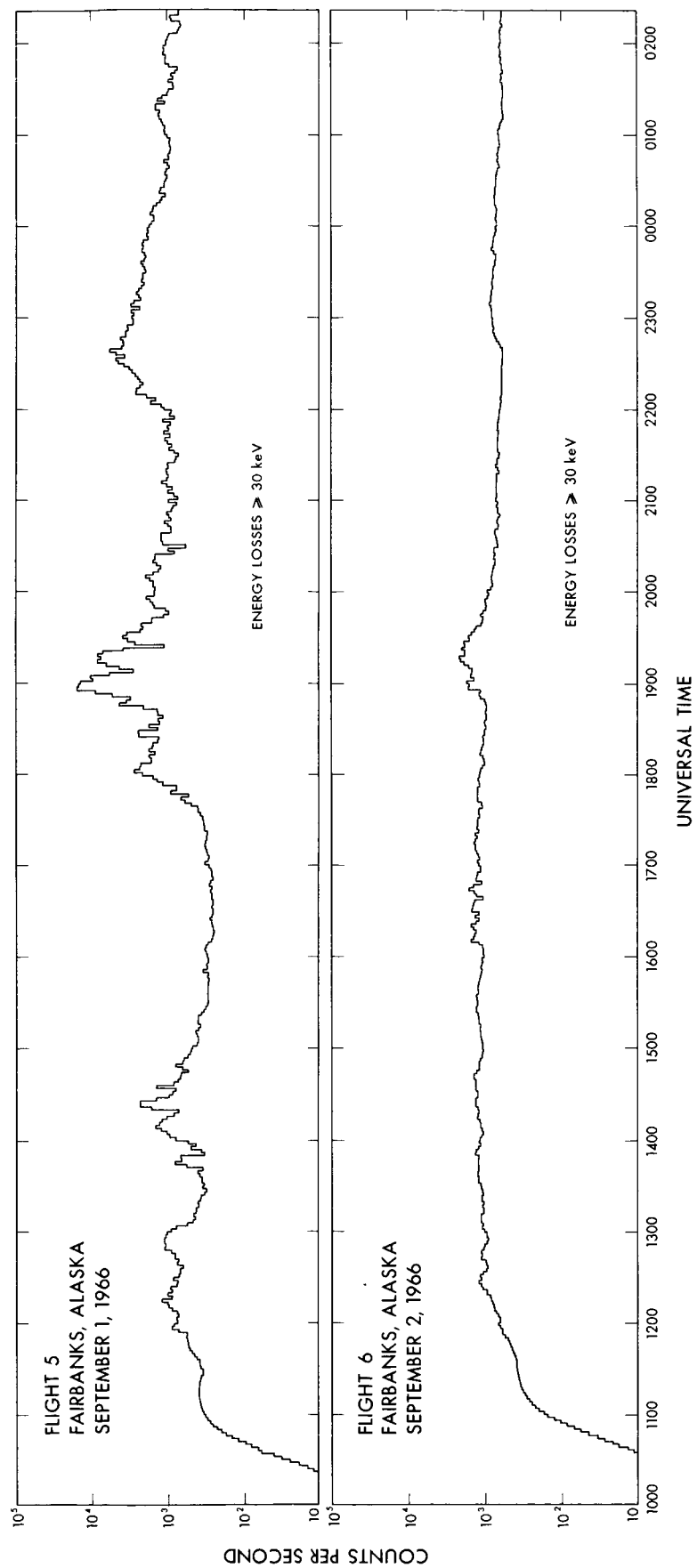


Figure 2

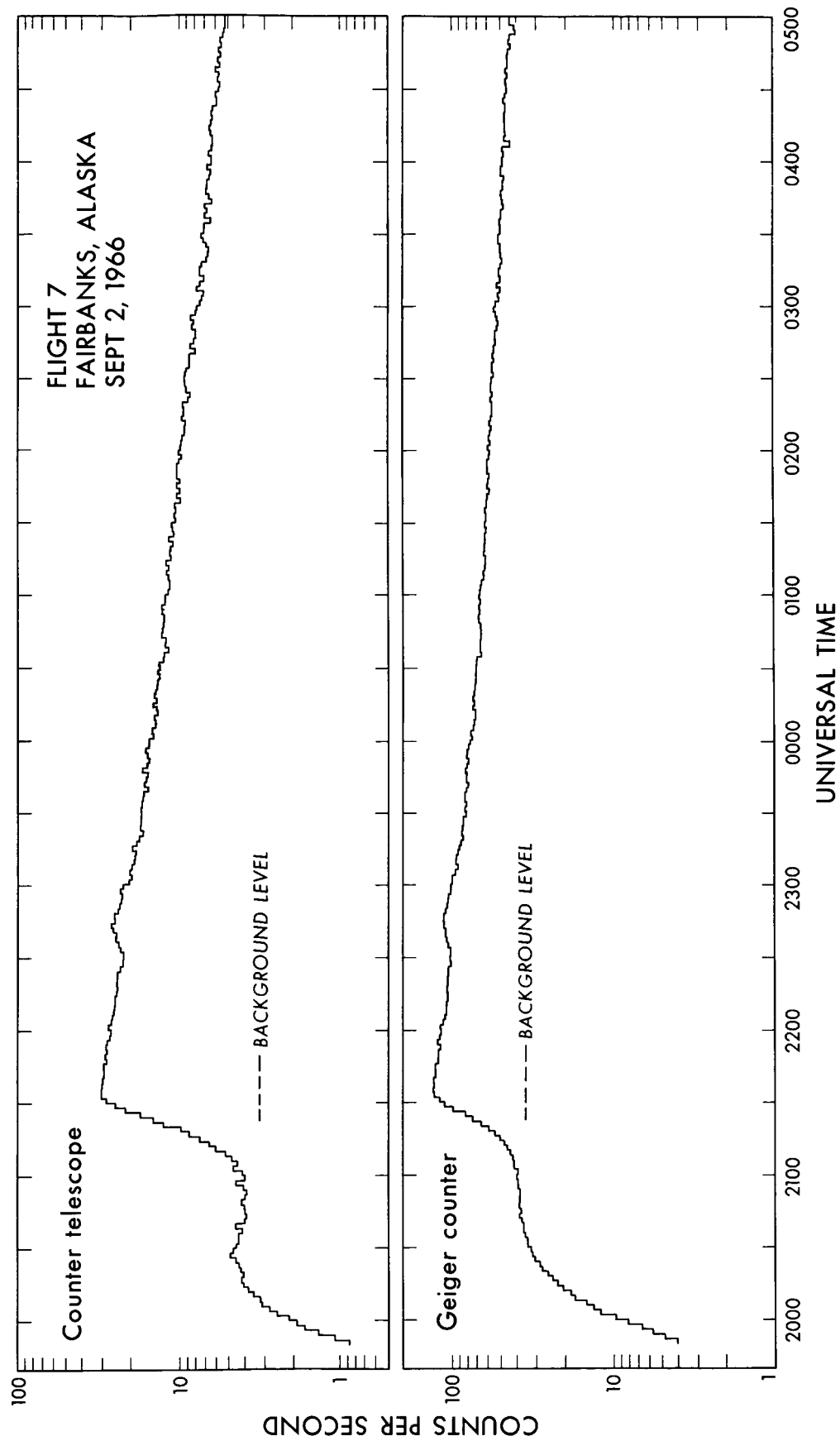


Figure 3

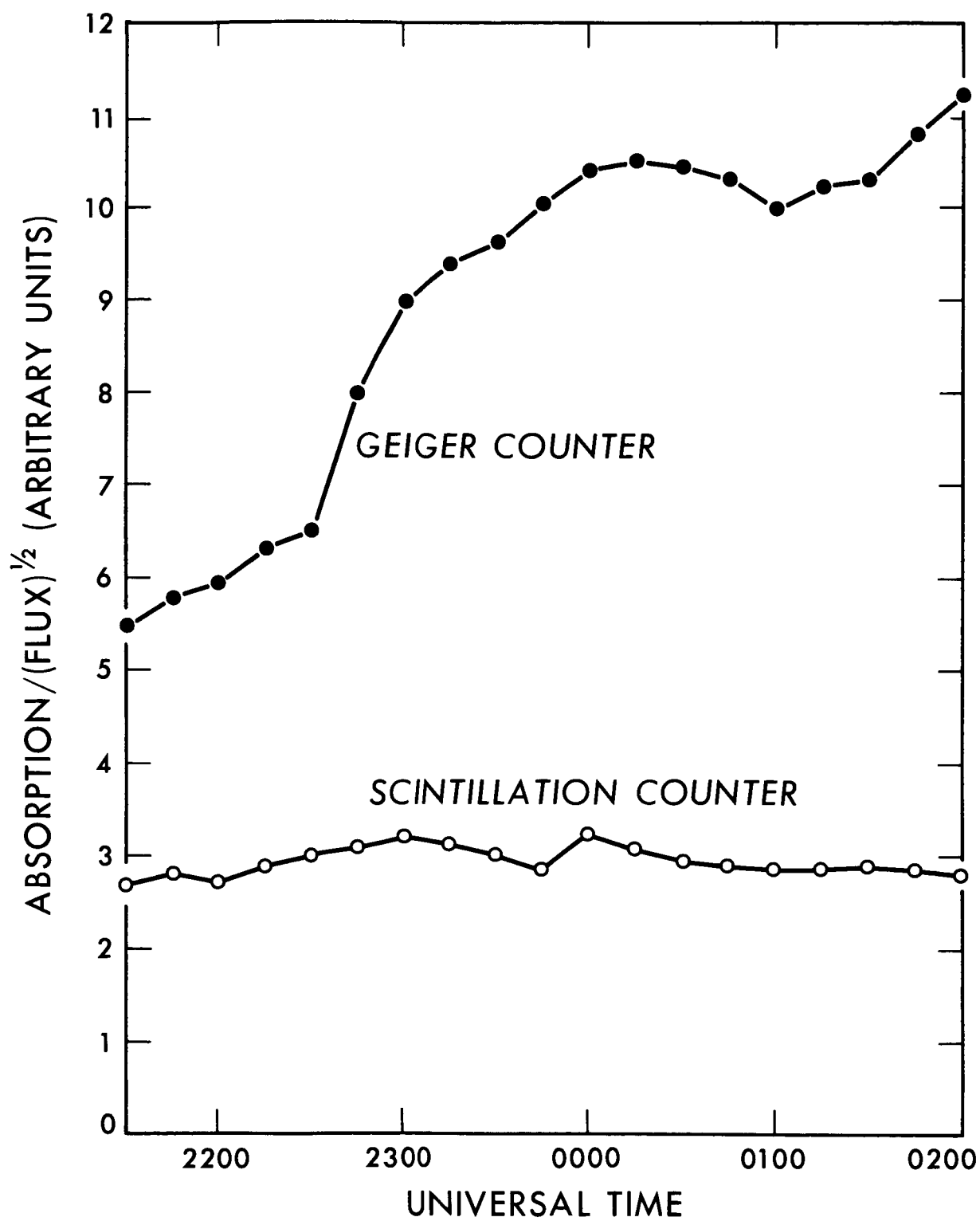


Figure 4

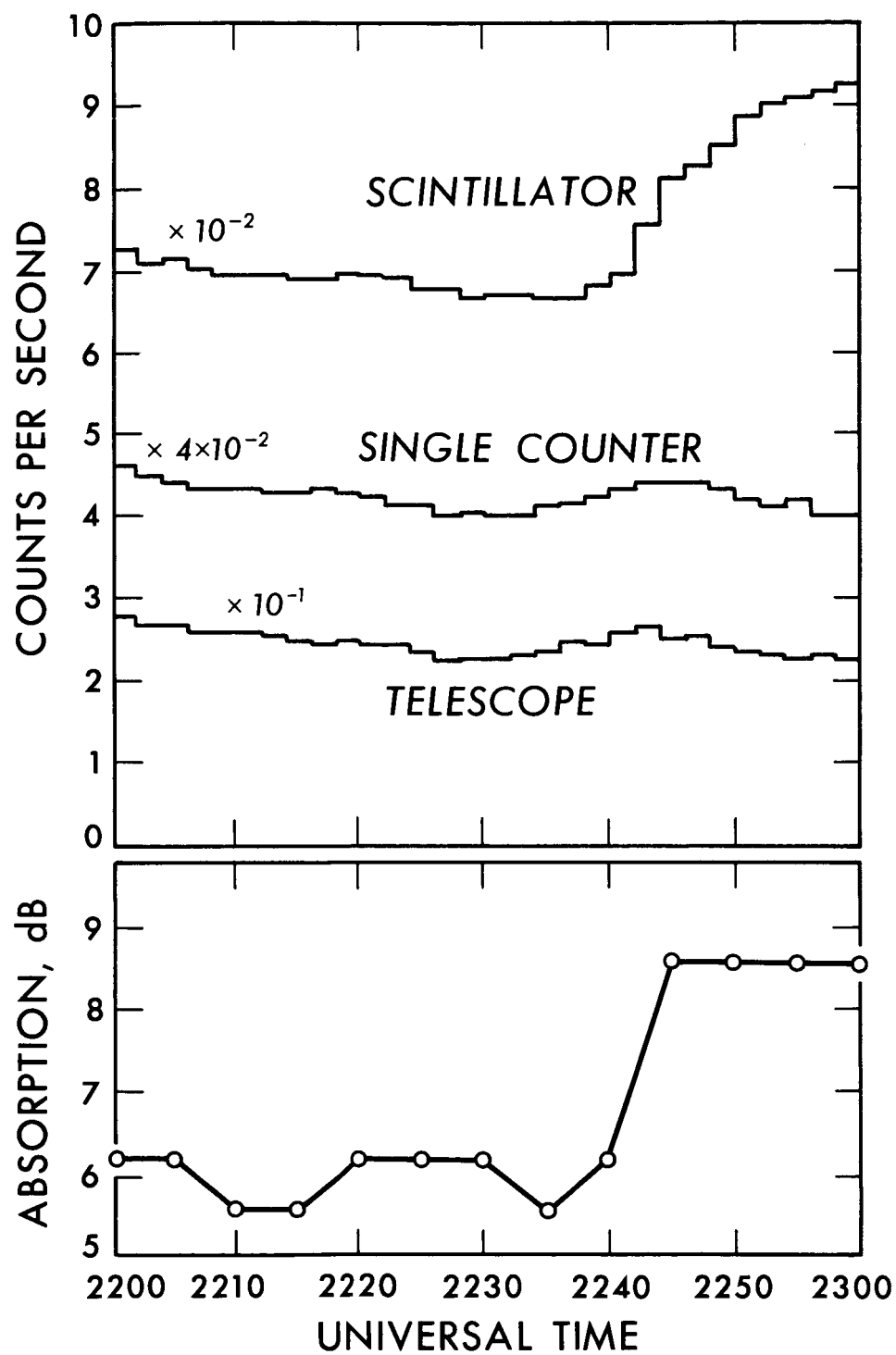


Figure 5

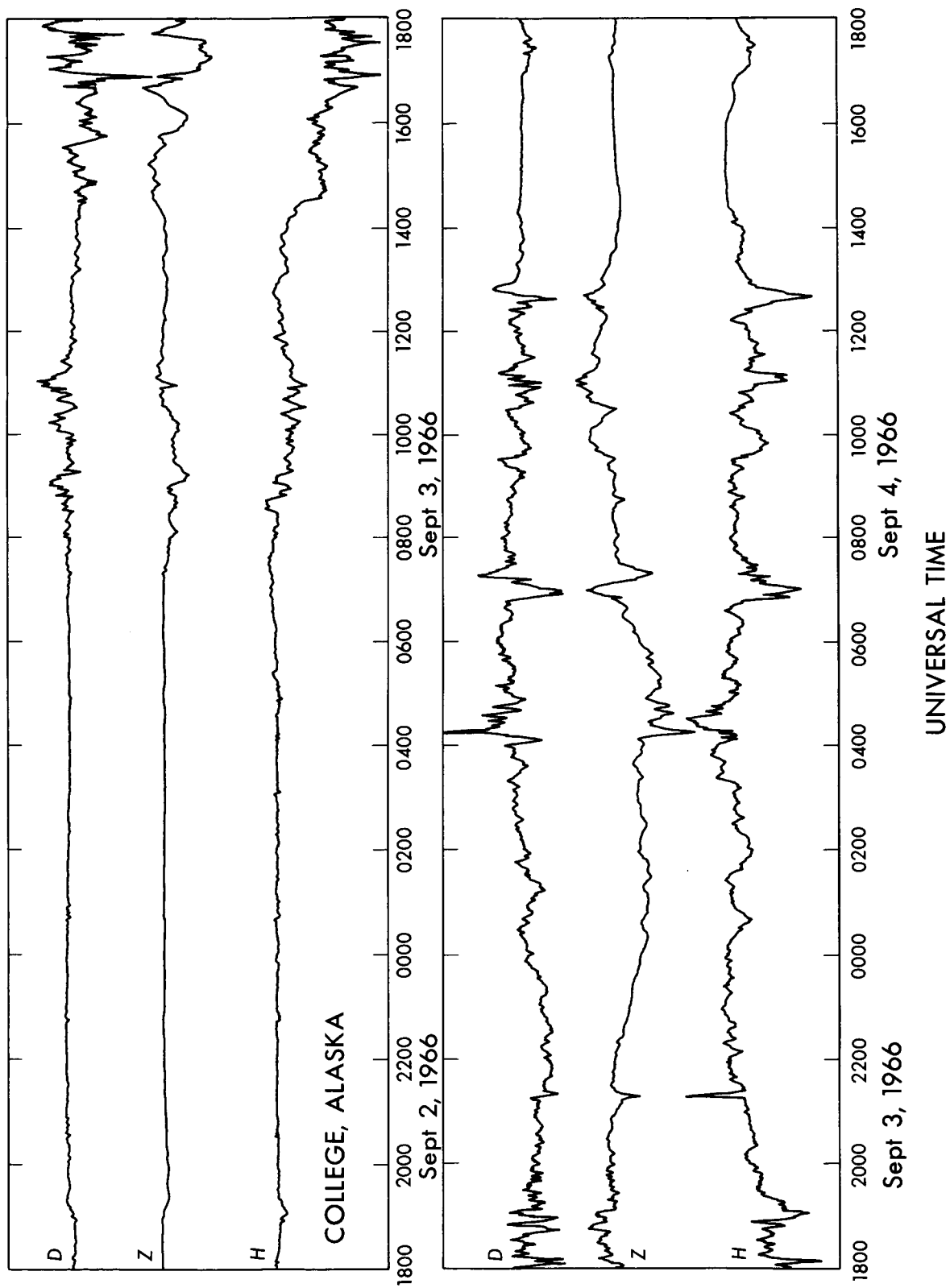


Figure 6